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AUTHOR Steinberg, Melvin S.
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ABSTRACT

Misconceptions associated with the origins of force and the effectiveness of a bridging strategy for developing correct conceptual models in mechanics are identified for high school physics teachers in this paper. The situation investigated was whether a table exerts an upward force on a book. Student misconceptions related to this phenomenon as well as student arguments based on causal reasoning reflecting a unitarian conception of matter are stated. These explanations are contrasted with arguments derived from a unitarian application of the force concept to motion-related effects rather than to the causes of force. An analysis is given of student response to this problem based on five high school physics classes. The merits of this type of lesson are also specified.
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THE ORIGINS OF FORCE -- MISCONCEPTIONS AND CLASSROOM CONTROVERSY

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Melvin S. Steinberg

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THE ORIGINS OF FORCE -- MISCONCEPTIONS AND CLASSROOM CONTROVERSY

Melvin S. Steinberg
Physics Department, Smith College, Northampton, MA 01063

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Introduction

I am speaking as a member of a multi-professional group based at the University of Massachusetts. We use videotape analysis of high school physics classes to study the effectiveness of a "bridging" strategy for developing conceptual models in mechanics. The project is led by John Clement. The bridging strategy was suggested by Clement's studies of analogical reasoning employed by experts to deal with novel situations.

Any curriculum that attempts to introduce new concepts must present students with novel situations. This has led Clement to conjecture that students -- like experts -- might profit from thinking about "bridges". A bridge is an intermediate situation that serves to reduce the conceptual distance between an "anchor" situation that is well understood and a "target" situation which appears to be quite different.

The target situation that I shall report on is a book at rest on a table. This problem has been discussed by Jim Minstrell in The Physics Teacher. Our classroom teachers asked their students: Does the table exert an upward force on the book?

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The anchor situation offered by the teachers was a spring compressed by a person's hand. The bridges offered were first a slab of foam rubber placed under the book and then a "bendy" table that sags under the book's weight. Student involvement rose to a peak when the "bendy" table image was introduced. The controversy that emerged made it clear to us that the bridging process was generating strong cognitive conflict over the physical role of the table.

The barrier misconception

Most of the arguments against the existence of a force exerted by the table seem to regard springs as seats of activity, but categorize rigid-appearing objects as simple barriers. The table is believed to be incapable of exerting force because it is perceived to be incapable of self-reversible deformation. Here are some examples:

"If you raise your hand the spring will bounce back, but the table won't move. If you put something really heavy on that table, then it's still going to hold it up. But it's still not deciding how much force. It can't! It's not alive -- it's dead."

"Gravity affects the spring differently from the table. Even if there was enough force to crush the table, it wouldn't pop back up."

"When you compress the spring it has to uncompress because it doesn't like being compressed. But the table is used to being like that."

"The spring has the potential of moving the hand, but the table doesn't have the potential of moving the book."

These students operate with a qualitatively different model from that of elastic deformation. The intensity with which their remarks were delivered suggests that the bendy table was threatening the speakers' dualistic conception of rigidity and springiness. It revealed to us that this dualism is deep-rooted to an unanticipated degree.

The open-ended discussion by which the bridging strategy was pursued also had the hoped-for effect of bringing out peer confrontation to challenge the barrier misconception. The students who were for the existence of a force exerted by the table employed two distinctly different types of reasoning, which I shall call "causal" and "logical".

Causal reasoning

The causal-reasoning students supported a unitarian conception of matter. Their arguments appear to be based on (1) a mechanism of self-reversible deformation and (2) an intuition that the table compresses or bends even though one can't actually see the deformation. One student proposed:

"With the bendy table it's just magnified more so you can see it, and on the hard table its just an insignificant amount of movement but the same amount of force."

When a detractor retorted "So wouldn't you call 'an insignificant amount of bending' none?" the reply was:

"Well, it's not measurable but it's still a force. The force exists."

When the detractor continued that a "strong enough" table wouldn't bend at all, a second student responded:

"Sure, it would bend a tiny, tiny -- almost insignificant -- amount, but because of the material it's made out of it equals the same amount of force."

In response to a further objection that a "solid" table can't move, the first student then added:

"Remember like in chemistry. You can't see it, but the atoms actually are bending, but not much. But it does happen, and it is a force that is there."

This classroom vignette demonstrates the vigor and focus of classroom controversy that can be instigated by a skilled teacher. It also reveals the strengths of causal reasoning: (a) Downplaying of perceptual differences in favor of a universal mechanism. (b) Reliance on analogy, which makes reasoning adaptable under attack. (c) Visualizability of mechanisms, which makes models capable of elaboration.

Logical reasoning

Now, let's listen to a qualitatively different type of argument for the existence of a force exerted by the table:

"At a certain point the force pushing on the hand and the spring -- they have to be equal, because the hand can't push the spring any farther down. And if the table weren't exerting some kind of force on the book, then the book would go down."

Students who reason this way seem to be searching for a structure of relationships that permits a unitarian application of the force concept to motion-related effects rather than to the causes of force. I am using the adjective "logical" to describe this type of reasoning because it appears to be more about form than about reality. The central argument among students in this category is that the force of gravity must be cancelled by an upward force in order for the book to remain at rest, regardless of the origin of the force. Here are some more "logical" arguments:

"Does it matter whether it [the table] moves or not? Isn't the point just that its holding it [the book] in a position that it doesn't want to be in, and if you took the table away it would fall down? The table is holding it up whether it moves or not."

"If you drop the book [onto the table], some force pushes it down." But then you need another force to stop it, and "That might as well be from the table."

One student also offered the following formal analogy to velocity addition:

"One way to sort of look at it is that if we are assuming the table is giving a force up, then you think of it sort of like [a boat trying to move upstream on] the river. The book is pushing down, say with, uh -- it's a little far-fetched, but with the velocity of the engines -- and the table is pushing up with the velocity of the current."

Non-causal arguments like these occur spontaneously. They seem to play a useful role in moving students toward an adequate operational definition of force. By themselves, however, they are not powerful enough to overthrow the barrier misconception. We feel that instruction should strive to provide all students with an intuitive basis for causal reasoning.

Progress on a make-sense scale

Did our experimental lesson succeed in moving students closer to the view of elastic normal force employed by physicists? Five high school physics classes with two different teachers voted six times during the lesson on the degree to which it "makes sense" to say that the table pushes upward on the book. We believe these classroom votes are valid instruments, because students do not appear to view make-sense questions in a grade-like way. There were large make-sense

gains in all five classes, and these look like they will be statistically significant when our quantitative analysis is completed.

I would like to speculate about why this lesson of less than 50 minutes was so productive. It looks like there may be two types of students in a typical physics class -- one oriented toward causal reasoning and the other toward logical reasoning. Their combined peer attack can provide a powerful challenge to belief in the barrier model. I also suggest that having to listen to unfamiliar arguments coming from peers (rather than from teachers) can push both pro-force groups toward a more adequate conception that integrates the causes of force with effects on motion.